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BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

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PROGRAMME OF THE
OAK RIDGE MEETING

AT

OAK RIDGE

TENNESSEE

March 16–17–18, 1950

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MARCH 16, 1950 Vol. 25, No. 2

BULLETIN

OF THE

AMERICAN PHYSICAL SOCIETY

OAK RIDGE MEETING, MARCH 16–17–18, 1950

THE **298th meeting of the American Physical Society** will be held at Oak Ridge, Tennessee, on Thursday, Friday, and Saturday, March 16, 17, and 18, 1950. Oak Ridge has not hitherto been host to our Society, but our Southeastern Section enjoyed its hospitality two years ago. We are heavily indebted to the Oak Ridge Local Committee, comprising E. J. Murphy and Hugh Henry and doubtless others also.

Reservations for housing and banquet. The Oak Ridge Local Committee is faced with problems not confronted by those of other communities which we visit, for it must arrange for housing and transportation as well as for meeting places and the banquet. It requires the cooperation of all who come to the meeting.

Mr. Hugh Henry (P.O. Box P, Oak Ridge, Tennessee) must be notified in advance: (a) of the time of your arrival and the place—Knoxville railway-station or Knoxville airport; (b) of the number of nights you will spend at Oak Ridge; (c) whether or not you wish to attend the banquet of Friday evening. Limousines (fare $2 or thereabouts) will be sent to the railway station and to the airport to meet the trains and planes by which members are known to be coming: they will find out where they are to stay when they get there. Those who come by car should go first to Claremont Hall; maps will be sent to them by Mr. Henry if they ask him.

The **registration desk** will be set up in the Ridge Recreation Hall. All members are asked to register and frequently to consult the bulletin board for notice of messages.

The **banquet** will be held on the Friday evening, preceded by a cocktail-party which will commence at 6 P.M.; the price of the whole is four dollars. The Local Committee plans a smoker for the Thursday evening from 8 to 11.30 P.M.

Solid-state physics will predominate at this meeting, but will not monopolize it. Our Division of Solid-State Physics (which incidentally holds its Annual Meeting as a part of ours) has organized three symposia, or rather a single symposium of very broad coverage, which will extend over Thursday afternoon, Friday morning, and Friday afternoon. Some two-thirds of the 57 ten-minute papers also belong to this field, and accordingly we have been obliged to have simultaneous sessions in solid-state physics: the Secretary, with the help of the Chairman of the Division, has tried so to dispose them as to minimize the disadvantage.

Nuclear physics has a symposium on "Nuclear Disintegrations of Extreme (i.e., extremely short and extremely long) Half-Lives," including also a paper on double-beta-decay. This was arranged with the advice of A. M. Weinberg and M. Goldhaber, and is scheduled for Saturday morning.

The **Council of the American Physical Society** will meet in the Conference Room of the Oak Ridge Institute for Nuclear Studies on the Thursday morning, and cars will be provided at 10 A.M. at the Guest House to take its members thither.

Post-deadline papers will be considered for acceptance (or rejection) if abstracts thereof are received at the office of the Society not later than 9 March. This privilege is accorded only in favor of very recent achievements of very special importance: it is not intended to provide a second opportunity for members who just failed to get their abstracts in on time. The abstracts will not be published. The titles of such papers as are accepted will be announced on a blackboard near the registration desk, and the papers will be given under the usual ten-minute rule after Session E.

Prospective meetings of the Society are scheduled for Washington, D. C., April 27–29, and Mexico City, June 21–24.

General Rules Relating to Papers

The time allowed for the oral presentation of a contributed paper is ten minutes at most. The time

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allowed for the presentation of each invited paper is stated in the Bulletin.

When two or more contributed papers are submitted by the same member, all but one are placed on the "supplementary programme." (A paper by two or more members is credited, for this purpose, to the person first named in its by-line.) For each paper on this programme a session is indicated, at the end of which it may be offered: but the Chairman of the session may allot to it less than ten minutes, or may read it by title.

Titles and abstracts of the papers contributed to the 1950 Oak Ridge meeting are printed hereinafter. For the last time, proofs are being submitted to the authors so that they may correct misprints or errors before the abstracts appear in *Physical Review*. A new procedure is described near the bottom of this page, and will prevail till further notice.

Speakers must retrieve their lantern slides before leaving the hall in which their papers were given. The Local Committee must not be burdened with the task of saving and returning them.

KARL K. DARROW, *Secretary*
Columbia University
American Physical Society
New York 27, N. Y.

New Policy Pertaining to Abstracts

Beginning with the next (Washington) Bulletin and continuing until further notice, the abstracts printed in the Bulletin will be republished in *Physical Review exactly as they stand in the Bulletin*. Proof will no longer be submitted to the authors. Those authors who notice misprints or errors in their abstracts may send "errata" to the American Institute of Physics for publication on a page of the *Review* adjacent to the abstracts. These must be addressed to Miss Ruth Bryans, American Institute of Physics, 57 East 55th Street, New York 22, New York; they will be disregarded unless received not later than the second Friday after the close of the meeting. "Errata" means corrections of *errors:* it does not signify an opportunity to rewrite the abstract in order to include results not obtained at the time when the abstract was written.

This policy will save the Society a sizable amount of money over the present one. It will cause trouble to people who do not conform to the rules governing the length of abstracts and the "word equivalents" of footnotes and display formulas. These rules are intelligibly set forth on every summons card. The Secretary sometimes abridges an overlong abstract in preference to rejecting it, but has neither the wisdom nor the time to rewrite an abstract in such a way as to cover the most important points in fewer words. It would be helpful to the editors if our members would also observe how abstracts are printed in the Bulletin. Preface your abstract with the title of the paper, followed by your name in capitals, followed by the name of your institution (but not its address!) underlined to indicate that the printer is to use italics. Type your abstract with double spacing. Do not let it sprawl over two pages: if it cannot be fitted into one page it is too long. Do not make the abstract a part of your covering letter: the editors have to delete the redundant material. Do not include a contract number: nobody is interested in it. Do not forget to send two copies of your abstract to the office of the Society.

EPITOME OF THE MEETING

(Personal names are those of invited speakers.)

Thursday Morning

A. Solid-state physics, largely metallurgical. Centre Theatre.

Thursday Afternoon

B. Symposium on solid-state physics: Lark-Horovitz, Shockley, Smoluchowski, Zener. Centre Theatre.
C. Nuclear physics. Ridge Hall, East Lounge.

Friday Morning

D. Symposium on solid-state physics: Warren, Seitz, Shull, Anderson. Centre Theatre.
E. Various topics. Ridge Hall, East Lounge.

Friday Afternoon

F. Symposium on solid-state physics: Williams, von Hippel, Slater, Bloembergen. Centre Theatre
G. Miscellany in electron physics and solid-state physics. Ridge Hall, East Lounge.

Friday Evening

Banquet of the American Physical Society: Weinberg. Oak Terrace Restaurant, Grove Centre.

Saturday Morning

H. Symposium on beta-emission: Konopinski, Bell, Axel, McGowan and De Benedetti, Fireman. High School Auditorium.
I. Semi-conductors. Ridge Hall, East Lounge.

PROGRAMME

THURSDAY MORNING AT 10:30

Centre Theatre

(A. W. LAWSON presiding)

Solid-State Physics, Largely Metallurgical

A1. Low Temperature Oxidation of Copper. T. N. RHODIN, JR., *University of Chicago (Introduced by A. W. Lawson).*—The formation of thin stable oxide films on small single crystal plates of copper has been studied in the temperature range 78°K to 300°K. The surface areas were determined from micro-adsorption isotherms of nitrogen and argon at 78.1°K and 89.2°K. The rate isotherms were followed with a quartz vacuum microbalance. Oxidation was extremely rapid at first but after a few minutes dropped to negligible values, a stable film being formed with a limiting thickness from 5A to 50A with an error of 3 percent. An explanation of this behavior was first given by N. F. Mott (1947) and depends on the hypothesis that a strong field is set up in the oxide film which enables the metal ions to move through it without much help from temperature. A modified oxidation rate expression based on that hypothesis was found to be valid in this case: $dx/dt = A \exp(-W/kT) \exp(V/xT)$, where x = film thickness, t = time, V = contact potential, T = temperature, W = activation energy, A = proportionality constant. The energy of activation for oxidation (1.1 ev) and the contact potential (0.7 v) between copper and cuprous oxide were calculated from the experimentally determined oxidation rates and the values of the effective limiting oxide thickness. (Army Air Force Contract.)

A2. Growth of Alkali Halides onto Single Crystal Substrates. L. G. SCHULZ, *University of Chicago.*—During a study of the mechanism of crystal growth from the vapor state eight different alkali halides were deposited by evaporation in a vacuum onto cleavage surfaces of single crystal substrates of LiF, NaCl, KCl, and KBr. Using electron diffraction it was found that for all combinations of substances examined the crystals in a deposit below 100A in thickness were oriented with their axis parallel to those of the substrate. This was true even for substances having widely different lattice constants, a_0. For example, KBr (a_0 equal to 6.58A) was found to orient on LiF (a_0 equal to 4.02A). With the technique employed it was possible to examine deposits ranging in average thickness from a few angstroms up to several thousand angstroms. When the atomic mismatch at the interface exceeded about 20 percent the following sequence of orientations was observed: below a thickness of 100A, complete orientation; in the range 100A to 300A, [100] fiber structure; and above 300A, a continuous change toward random orientation with increased thickness. When the mismatch was less than 20 percent there was complete orientation below about 200A; above that thickness there was a gradual change to random structure.

A3. Magnetostriction of Permanent Magnet Alloys. E. A. NESBITT, *Bell Telephone Laboratories.*—In order to obtain a better understanding of the mechanism of coercive force in modern permanent magnets, magnetostriction measurements have been made on various alloys having coercive forces from 50 to 600 oersteds. The results can be summarized by discussing two types of alloys. First are the older carbon-hardening permanent magnets and for these alloys high coercive force and high magnetostriction occur together. Second are the newer carbon-free permanent magnets, and for these alloys high coercive force does not occur with high magnetostriction. In fact for the Mishima alloys having compositions near 29 percent nickel, 12.5 percent aluminum and 58.5 percent iron and cooled at the rate of 3°C per second (coercive force, 400 oersteds) the magnetostriction actually passes through zero. This is contrary to the classical strain theory of coercive force which states that the latter is proportional to the product of the magnetostriction and internal stress. To explain the mechanism of coercive force for these alloys it is necessary to resort to more recent theories.

A4. Statistical Theory of Magnetic Saturation in Alloys. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.*—It has been previously shown* that various magnetic properties in a binary alloy depend upon the state of order. The theory indicates that the local electron concentration rather than the average electron concentration plays the main role. This paper is concerned with the statistical interpretation of the experimental saturation magnetization in several alloys. The theory is based on the calculation of the probability of various fluctuations of the electron density by taking into account the nearest and the second nearest neighbors in a body-centered lattice. These probabilities together with the band theory interpretation of the saturation moments allow to deduce the relation between local electronic density and the saturation moments. The agreement with experiment is satisfactory.

* J. E. Goldman and R. Smoluchowski, Phys. Rev. **75**, 140, 310 (1949).

A5. A Pulse-Annealing Method for the Study of Changes in Physical Properties Resulting from Heat Treatment.* N. S. RASOR AND W. E. PARKINS, *North American Aviation, Inc.*—An apparatus has been designed for the precise measurement of thermal conductivity, electrical resistivity, and thermoelectric power of small specimens near room temperature and in a vacuum. These specimens are then heated in place for short periods to specified temperatures. After cooling, the changes in these physical properties resulting from the annealing pulse are determined. The apparatus and method are useful in the comparison of changes in physical properties which occur simultaneously during a particular heat treatment. Rates of recrystallization, phase change, or chemical reaction occurring within the specimen can be determined. Measurements are made on a specimen volume of 0.008 cc. The present method is limited to materials which can be heated directly by an electric current. It has been found informative to determine the property changes resulting from single pulses to successively higher temperatures. Measurements have been made utilizing one minute pulses and 25°C temperature increments to as high as 2000°C. Special features of the design reduce heat losses sufficiently to permit measurement of very small thermal conductivities.

* Research carried out under contract with the AEC.

A6. The Crystallographic Mechanism of the Martensite Transformation in Iron-Carbon Alloys. J. S. BOWLES, *University of Chicago.*—Determination of the crystallographic mechanism of the martensite transformation in iron-carbon alloys involves the determination of: (1) the total atomic dis-

placements; (2) the paths taken by the atoms during these displacements. Further confirmation of Jaswon and Wheeler's[1] minimum displacements hypothesis is given by demonstrating that these displacements produce the lattice-plane transformations determined by Greninger and Troiano.[2] These displacements cannot occur as a simple homogeneous distortion since this would not be consistent with the observed relief effects produced by the transformation. Geometrical consistency can be achieved by ascribing paths to the atoms during these displacements. Certain assumptions are made which permit these paths to be determined from a stereographic analysis of the Kurdjumow-Sachs orientation relationship, and the conclusion is reached that each atom moves first in the austenite twinning direction and then in the martensite twinning direction. The proposed mechanism is consistent with all the geometrical features of the transformation; good agreement is found between the predicted and observed angles through which polished surfaces are tilted by the production of martensite plates.

[1] M. A. Jaswon and J. H. Wheeler, Acta Cryst. 1, 216 (1948).
[2] H. B. Greninger and A. R. Troiano, Trans. A.I.M.E. 185, 590 (1949).

A7. Transformation Characteristics of a Lithium-Magnesium Alloy. C. S. BARRETT AND D. F. CLIFTON, *University of Chicago.*—Further investigation by x-ray spectrometry has disclosed new details of the diffusionless transformation in Li-Mg alloys.[1] Studies in an alloy containing 12.4 percent atom magnesium have shown that the temperature at which the transformation from cubic to hexagonal starts on cooling (Ms) is independent of cooling rate between about 1° and 30° per min. However, Ms is altered by annealing at different temperatures prior to cooling, even when this annealing does not alter the grain size or cause recrystallization. The transformation on heating, as on cooling, proceeds only with changing temperature; starting with some cubic phase present, the transformation at first proceeds slowly with changing temperature; then, at a temperature above Ms, the rate becomes quite rapid but slows again near completion. The curve of hexagonal to cubic transformation shifts to higher temperatures when the alloy is carried to lower temperatures before heating. If heating is stopped while some hexagonal remains and is followed by cooling, the formation of hexagonal begins at a temperature Ms′ which lies 0° to about 18° above the normal Ms; Ms′ increases with increasing amounts of the hexagonal phase at the beginning of the cooling.

[1] C. S. Barrett and O. R. Trautz, Trans. A.I.M.E. 175, 579 (1948).

A8. The Hydrogen Permeability of Zirconium.* R. B. BERNSTEIN AND DANIEL CUBICCIOTTI, *Illinois Institute of Technology.*—The rate of permeation of hydrogen through ductile zirconium sheet was measured over the temperature range 400–900°C. Fore-pressures up to 0.5 atmos. were applied to the specimens, which were disks of 0.71 cm² exposed area, 0.13 mm thick. The back-pressure was maintained near zero. The permeabilities ranged from 10^{-5} to 10^{-1}-cc atmos. (NTP)/cm² sec. The rate of diffusion was found to decrease with time in an approximately exponential manner, with a "half-time" of about 1.5 hr. Considerable variation in the permeability of successive samples was observed. The differences were attributed in part to differences in surface contamination. At constant temperature the flow rate was found to be proportional to the square-root of the hydrogen pressure, in agreement with similar results reported for other hydrogen-metal systems. The apparent energy of activation for the permeation process, estimated from the data, appeared higher than anticipated from existing data on other metals.

* This research was carried out under the sponsorship of the ONR.

A9. Diffusion of *C* in α-Iron. CHARLES WERT, *University of Chicago.*—The diffusion coefficient, D, of C in α-iron has been measured in the neighborhood of room temperature by means of relaxation phenomena. Together with data of Stanley,[1] these measurements extend over a range of temperature from −35°C to 800°C. The range of D is from 10^{-20} cm²/sec. to 2×10^{-6} cm²/sec. The data are found to fit the equation

$$D = D_0 \exp(-H/RT), \qquad (1)$$

where $D_0 = 0.02$ cm²/sec. and $H = 20{,}100$ cal./mole. By use of a classical statistical mechanical treatment of the problem of interstitial diffusion, an expression of type shown in Eq. (1) is derived for D. Contrary to some other treatments of this problem, the present investigation shows D_0 to be independent of the absolute temperature. The present measurements tend to confirm this, but the evidence is not yet conclusive.

[1] J. Stanley, J. Inst. Metals (October, 1949).

THURSDAY AFTERNOON AT 1:30

Centre Theatre

(A. VON HIPPEL presiding)

Symposium of the Division of Solid-State Physics

B1. Nucleon Bombardment of Semi-Conductors. K. LARK-HOROVITZ, *Purdue University.* (35 min.)

2:10 P.M.

B2. Germanium Filament Experiments. W. SHOCKLEY, *Bell Telephone Laboratories.* (35 min.)

2:50 P.M.

B3. Recent Work on Diffusion. R. SMOLUCHOWSKI, *Carnegie Institute of Technology.* (35 min.)

3:30 P.M.

B4. Ring Diffusion in Metals. C. ZENER, *University of Chicago.* (35 min.)

Business Meeting of the Division of Solid-State Physics

THURSDAY AFTERNOON AT 2:00

Ridge Hall, East Lounge

(A. M. WEINBERG presiding)

Nuclear Physics

C1. The Isotopic Analysis of Nitrogen by Means of a Microwave Mass Spectrograph. A. L SOUTHERN, H. W. MORGAN, G. W. KEILHOLTZ AND W. V. SMITH, *Union Carbide.*—Microwave techniques have been applied to the isotopic analysis of nitrogen 14 and nitrogen 15 in ammonia. The calibrations required and precision obtained are described for the range 0.38 to 4.3 percent nitrogen 15. The microwave spectrograph is discussed in relation to the use of stable isotopes as tracer materials.

C2. Two Group Equations for the Diffusion of Neutrons in a Multiplying Medium.* E. RICHARD COHEN AND M. A. GREENFIELD, *North American Aviation, Inc.*—The diffusion of neutrons in a multiplying medium are usually approximated by replacing the slowing down process by a monoenergetic group of neutrons in which the slowing down is a mechanism which couples this group with the thermal group.[1] If one starts with the more exact "age" equation and integrates over the energy, the fast group can be defined in a way which makes maximum use of the information available. Both fission and non-fission capture of neutrons in the slowing down range can be incorporated into the theory. The net result is to give simultaneous coupled differential equations for the thermal neutron flux, nv_{th}, and the mean slowing down flux per unit energy range, nv_f. These equations are formally the same as in the usual theory, but with a redefinition of constants.

* Research carried out under contract with the AEC.

[1] H. Soodak and E. C. Campbell, "Elementary pile theory," AECD 2201, p. 35.

C3. Neutron Energy Spectra. B. L. COHEN, C. E. FALK, AND S. K. KAO, *Carnegie Institute of Technology.*—Measurements were made of the energy distribution of neutrons obtained by irradiating various thick targets with 15-Mev deuterons from the University of Pittsburgh cyclotron. The low energy portion (2–12 Mev) was obtained by observing the recoil protons in photographic emulsions; the high energy spectrum (8–18 Mev) was determined from proton recoils in a triple coincidence-anticoincidence proportional counter telescope with aluminum absorbers. The combination of these two methods gives good statistical accuracy without large corrections over the entire energy range, and mutual check in the overlapping region. All spectra could be approximated by

$$I(E) = CEe^{-E/T} \qquad (1)$$

except at the extremities. As an example, for beryllium, $T = 2.7$ Mev. It will be shown that (1) gives good agreement with the predictions of nuclear statistical theories over most of the range, but represents a considerable deviation in the high energy region. Some modifications of (1) in the low energy region will also be discussed. This work was carried out with the assistance of ONR.

C4. Studies of Neutron Diffraction by Some Nuclei with Zero Spin. W. C. KOEHLER, E. O. WOLLAN, AND C. G. SHULL, *Oak Ridge National Laboratory.*—The accurate determination of the absolute intensity of the reflections in powder patterns presented difficulties in x-ray diffraction studies and it also presents some difficulties in corresponding neutron studies. It has been found convenient in the neutron case to normalize the observed counting rates in the patterns of samples of unknown cross section to the counting rates given by a sample for which the coherent cross section has been directly determined by transmission measurements. This can conveniently be done with powdered samples containing elements with a single isotope with zero spin and hence for which there is no isotopic or spin dependent diffuse scattering. The transmission cross section and the intensities of the powder patterns are being studied for a number of samples satisfying the above conditions and the consistency of the results obtained will be a factor in determining the over-all accuracy of coherent cross-section measurements by the crystal powder diffraction technique. Results with the oxides of Th and of the separated isotopes of Ca and Ni will be reported.

C5. Nuclear Radiations in Well Logging. CLARK GOODMAN, CHARLES W. TITTLE,* AND HENRY FAUL,† *Massachusetts Institute of Technology.*—The penetration of solid materials by neutrons and gamma-rays has been applied as an empirical index of subsurface structure and composition surrounding cased drill holes. Counters and ionization chambers have been used to detect gamma-rays from the formations. Similar probes detect gamma-rays emitted when neutrons from a portable source are captured in surrounding materials. Studies are being made under conditions that simulate field operations. Although this work is still in the initial stages, certain conclusions are appearing: (1) The possibilities and limitations of present logging techniques can be established; (2) by improvements in present operating procedures increased knowledge of subsurface conditions should result; (3) neutron flux measurements should provide additional information of practical value; (4) such measurements, when made simultaneously at several points along the axis of the drill hole in the vicinity of a porous formation, can, under favorable conditions, distinguish between oil (and/or fresh water) and salt water.

* Gulf Fellow in Physics 1944–1948, present address: North Texas State College, Denton, Texas.

† Present address: U. S. Geological Survey, Washington, D. C.

C6. Measurement of Fast Neutron Dosage to Tissue with a Proportional Counter. G. S. HURST, *Oak Ridge National Laboratory (Introduced by K. Z. Morgan).*—Calculations indicate that a proportional counter can be so designed that the response to fast neutrons gives an approximate measure of the radiation dosage that the neutrons would give to tissue. This implies that the counter must have an efficiency for fast neutrons that is the same function of their energy as is the reciprocal of the neutron flux required for a given dosage rate. It has been shown that, in the energy range investigated, 0.2 Mev to 10 Mev, this function can be approximated with a practical counter chamber. One such chamber has one end lined with 0.017 cm of stearin, is 3.5 cm in length, and contains 18 cm (Hg) of methane. Application to neutrons of higher energy has not been investigated.

C7. Gyromagnetic Ratios of Vanadium^{51} and Manganese^{55}. WILLIAM H. CHAMBERS, ROBERT E. SHERIFF, AND DUDLEY WILLIAMS, *Ohio State University.*—Methods similar to those described in earlier reports have been used to observe nuclear magnetic resonance absorption peaks for V^{51} and Mn^{55}. The V^{51} peak was observed in a solid sample of V_2O_5. The value obtained for the gyromagnetic ratio of V^{51} is in agreement with values obtained recently in other laboratories. The Mn^{55} peak was observed with samples consisting of aqueous solutions of $Ba(MnO_4)_2$, $Ca(MnO_4)_2$, and $K(MnO_4)$. The most intense absorption peak was obtained with the $Ca(MnO_4)$ sample. Pre-

liminary results give the following value for the ratio of the resonance frequency of Mn^{55} to the proton resonance frequency in the same field: $\nu^{55}/\nu^{1}=0.24813\pm0.00014$. Further work on the subject is in progress.

C8. Beta-Gamma-Angular Correlations. DONALD T. STEVENSON AND MARTIN DEUTSCH,* *Massachusetts Institute of Technology.*—Angular correlations between beta- and gamma-rays have been studied using a magnetic lens spectrometer to isolate beta-particles in selected energy ranges. No anisotropy was found in the decay of Na^{22}, Cs^{134}, and Co^{60}. The two first named are known to emit beta-spectra of allowed shape so that no deviation from symmetry is expected. In the case of the lower energy branch of Rb^{86} the gamma-ray has a greater probability to be emitted along the direction of the emitted beta-ray than at right angles to it. The effect is greatest near the maximum energy of the beta-spectrum, the ratio $W(180°)/W(90°)$ reaching a value of about 1.2. For beta-rays of $\frac{1}{3}$ maximum energy this ratio drops to about 1.09. These findings contradict the results of Frankel.[1] Some general considerations concerning theory and technique will be presented.

* Supported in part by the Joint Program of the ONR and the AEC.
[1] S. Frankel, Phys. Rev. **77**, 747A (1950).

C9. Scintillation Spectra of Short-Life Activities. EDWARD C. CAMPBELL AND MAX GOODRICH,* *Oak Ridge National Laboratory.*—In order to study the radiations of radioactive substances having half-lives of the order of seconds, a new method has been devised which permits a complete spectrum to be photographed in a few seconds. The method consists in displaying the pulses from an anthracene scintillation counter on an oscilloscope using a self-triggered sweep. A short time-exposure photograph gives the pulse-height spectrum of the activity being studied. By calibrating with known radiations an energy *vs.* pulse-height relation is obtained, which is linear from 0.4 to 2.5 Mev. Energy measurements are reproducible to about 2 percent. The apparatus has been installed at the fast pneumatic tube of the Oak Ridge graphite reactor in order that samples can be observed beginning 0.3 sec. after irradiation. Using this method two gamma-rays associated with a new 0.9-sec. isomeric activity in lead have been found with energies of 0.5 and 1.0 Mev. The energy of the gamma-ray associated with the 24-sec. period of Ag^{110} is 0.66 ± 0.01 Mev in good agreement with the Ag^{110} decay scheme proposed by Siegbahn.

* On leave from Louisiana State University.

C10. Gamma-Spectrum of Barium 131. E. B. DALE, E. L. ZIMMERMAN, D. G. THOMAS, AND J. D. KURBATOV, *Ohio State University.*—Radioactive barium 131, $T_{\frac{1}{2}}\simeq12$ days, has been examined with a thin-lens spectrometer. The 364.18-kev gamma-ray emitted by iodine 131 was used for calibration of the spectrometer. The calibration was verified with cobalt 60 and scandium 46. The activated barium was obtained from the Oak Ridge National Laboratory. It was purified and the radioactive Cs^{131} was removed. An appropriate time was allowed for disintegration of barium 133. A tin radiator was used in the region up to 130 kev and a lead radiator up to 700 kev. It was found that in disintegration of barium 131 several gamma-rays are emitted. The 496.5-kev gamma-ray is several times as intense as others. K and L photoelectron peaks gave a consistent value for this gamma-energy of 496.5 ± 4 kev. Several other less intense gamma-rays were observed with consequent greater error in energy determination. The low specific activity of the Ba^{131} limited the precision of determination of energies of these less intense gamma-rays. Further work is in progress.

[1] Lind, Brown, Muller, and DuMond, Phys. Rev. **75**, 1633 (1949).

C11. An Excited State of Ta^{181} with 1.1×10^{-8}-Second Lifetime.* W. C. BARBER, *Stanford University.*—Using sources of Hf^{181} ($T=46$ days) some excited states of Ta^{181} have been investigated. Delayed coincidence measurements have been made with a system employing stilbene scintillation counters. Pulses from the counters are delayed in coaxial cable, amplified with fast amplifiers (distributed amplifiers of band width about 60 megacycles/sec.) and mixed in an electronic circuit. Curves of coincidence rate as a function of delay, taken with various sources, indicate that the resolving time of the system is about 1.3×10^{-8} second. Gamma-γ-coincidences taken with Hf^{181} as source indicate a metastable state of half-life about 1.1×10^{-8} second. Absorption in lead of the radiation following the metastable state is consistent with the interpretation that γ-rays of 470 and 340 kev follow this metastable state. Using a delayed coincidence system employing univibrators, the 22 μ-sec. level of Ta^{181} has also been investigated. Hard and soft γ-rays are found to follow this state, but no γ- or x-radiation is observed to precede it. The prompt β-(hard γ-) coincidences previously reported by the author were not observed in a second sample of Hf^{181} and were probably mostly due to an impurity in the original sample. This evidence indicates that, as first suggested by Chu and Wiedenbeck, most of the transitions from Hf^{181} lead directly to the 22 μ-sec. level of Ta^{181}.

* Assisted by the Joint Program of ONR and AEC.

C12. Steady High Magnetic Fields. MARTYN H. FOSS, *Carnegie Institute of Technology.*—With sufficient power, very high steady magnetic fields can be obtained. Consider the following dimensionless ratios characteristic of a design $h=H/(fj_0r_0)$, $p=P/(fr_0^3j_0^2\rho)$, $v=V/(fr_0^3)$. First determine h using the required field; the maximum space factor times current density; and the minimum inside radius. There is an ideal design for each h which uses the smallest power, P, for a given (sufficiently large) volume of conductor, V. A practical design can approach this efficiency. This work was carried out with the assistance of ONR and AEC.

C13. Synchro-Cyclotron Magnet.* M. H. FOSS, J. G. FOX, R. B. SUTTON AND E. CREUTZ, *Carnegie Institute of Technology.*—A synchro-cyclotron magnet designed[1] to produce 400-Mev protons at a field of about 20 kilogauss will be described. The full scale magnet has duplicated very closely the characteristics of the model. Curves will be shown which give the field shape for various absolute field strengths and at various distances from the geometrical mid-plane of the gap. The vertical distance within which magnetic focusing exists is about two inches. The probable maximum radius of the ion beam ($n=0.2$ point) is about 96 percent of the radius of the pole face at which point the field is about 96 percent of its value at the center. The radius of the pole face is 141.6 in. of the pole base 163.4 in. The total weight of the iron is 1500 tons; the copper 130 tons. The current is 20,000 amps. and the power consumption 320 kw.

* This work was carried out with the assistance of ONR and AEC.
[1] M. Foss, Tech. Report No. 1, Contract N7ONR30301.

C14. Integral Relationships Between Nuclear Masses and the Electron Mass. ENOS E. WITMER, *University of Pennsylvania.*—Recent experiments[1] show that the ratio of the proton mass to the electron mass is very close to 1836. We[2] believe that it is *exactly* 1836. This permits an accurate determination of m in mass units from H^1. Using this it is found that the mass of O^{16} is $(29155.018\pm0.080)m$. This is so close to an integer that we are justified in assuming that the nuclear mass of O^{16} is exactly $29147m$. This enables us to determine m in MU to an astounding degree of precision. We will now introduce a new unit of mass, namely $m/11$, which we shall designate *the prout*. This prout is about one-fourth of the prout previously used by the writer.[3] It appears to be true that *the masses of all nuclei, not subject to β-decay, are an integral number of prouts. Some of those subject to β-decay also follow the integral rule.* This fits in with the writer's general notion of the dominance of integers[2,3] in the nuclear domain.

[1] Hipple, Sommer, and Thomas, Phys. Rev. **76**, 1877 (1949).
[2] E. E. Witmer, Abstracts L7 and SP1, Bull. Am. Phys. Soc. **25**, No. 1, New York Meeting (February 2, 1950).
[3] E. E. Witmer, Proc. Nat. Acad. Sci. **32**, 283 (1946).

FRIDAY MORNING AT 9:30

Centre Theatre

(R. SMOLUCHOWSKI presiding)

Symposium of the Division of Solid-State Physics

D1. Order and Disorder in Alloys. B. E. WARREN, *M.I.T.* (35 min.)

10:10 A.M.

D2. Statistics of Luminescent Crystalcounters. F. SEITZ, *University of Illinois* (35 min.)

10:50 A.M.

D3. Neutron Diffraction Studies of Ferromagnetic and Antiferromagnetic Substances. C. G. SHULL, *Oak Ridge National Laboratory.* (35 min.)

11:30 A.M.

D4. Theory of Antiferromagnetism. P. W. ANDERSON, *Bell Telephone Laboratories.* (35 min)

FRIDAY MORNING AT 10:00

Ridge Hall, East Lounge

(I. I. RABI presiding)

Papers on Various Topics

E1. On the Heat of Devitrification of Aqueous Solutions. B. LUYET, *St. Louis University.*—When a droplet of a concentrated solution (we used 1.8 M sucrose) is cooled at a rate of several hundred degrees per second, it solidifies into an amorphous, transparent mass. Upon being rewarmed this mass devitrifies, becoming white and opaque (at −32°C for 1.8 M sucrose). In an attempt to estimate the heat of devitrification, we recorded photographically the warming curves of cylindrical pieces (1 mm thick, 3 mm diameter) of vitrified material in which one junction of a thermocouple, connected to a string galvanometer, was inserted, the other junction being either kept at constant temperature or inserted in a similar cylinder of water cooled and rewarmed simultaneously with that of solution. With this differential method the sensitivity of the string could be increased considerably. No change in the slope of the curves was detected during devitrification. Since the melting of the ice cylinder, which absorbed some 560 millicalories, lasted about 45 seconds (long plateau in the curve) in test experiments with ice alone, the heat of devitrification of the solution must be exceedingly little not to affect the curve. This raises the question of whether devitrification involves a crystallization of the solvent.

* Supported by Research Corporation.

E2. The Use of Three Long Narrow Coils for Neutralization of the Earth's Magnetic Field in a Beta-Ray Spectrometer. S. K. HAYNES AND J. W. WEDDING, *Vanderbilt University.*—Accurate neutralization of the earth's magnetic field over a long cylindrical region is necessary to extend the energy range of a magnetic-lens spectrometer to very low energy electrons. Three parallel rectangular coils are used.[1] The center coil has a width $2a$, a length equal to five times the width, and contains N turns. Each outer coil has a width $\sqrt{2}a$, the same length, and $N/\sqrt{2}$ turns. They are placed at a distance $a/\sqrt{2}$ on each side of the center coil. In a plane transverse to the length of the coils the radial variation of the field is given approximately by the term $H_0(r/a)^8$. This term gives variations of about plus and minus one percent separated by 30° azimuthally. With the coil current set for zero deflection for axial electrons, the rotation of the non-axial trajectories averages out these deviations so that the effective residual field is about 0.1 percent of the earth's field. For a one meter spectrometer 10-kev electrons are deflected 0.1 millimeter.

[1] J. H. Sweer, Naval Ordnance Memorandum No. 8582.

E3. Quantum-Electrodynamics. FREDERIK J. BELINFANTE, *Purdue University.*—In manifestly covariant quantum-electrodynamics, the vacuum is a superposition $\Psi=\Pi_{\mathbf{k}}(\Sigma_{mn}c_{mn}{}^{\mathbf{k}}\chi_{mn}{}^{\mathbf{k}})$ of states $\chi_{mn}{}^{\mathbf{k}}$ with m longitudinal positive energy photons and n "scalar" negative energy photons present with wave vector $\mathbf{k}$.[1] In zero-order approximation by $c_{mn}{}^{\mathbf{k}}=c_n{}^{\mathbf{k}}\delta_{mn}$ the energies of longitudinal and scalar photons cancel. Since in this approximation $c_n{}^{\mathbf{k}}=(-)^n c_0{}^{\mathbf{k}}$, Ψ is not properly normalizable. This fact may lead to mathematical ambiguities in the calculation of the electron self-energy.[1] These ambiguities now can be avoided at least formally, if in Eqs. (33)[1] we avoid the sums over n of terms with factors c^*c by writing them as vacuum expectation-values of products of photon annihilation and creation matrices $a_{\mathbf{k}}$, $b_{\mathbf{k}}$, $a_{\mathbf{k}}{}^*$, $b_{\mathbf{k}}{}^*$ describing the transitions listed under A-I[1a]. Taking along these expectation values through the calculation, using only the commutation relations of a, a^*, b, b^*, we find for the electron self-energy the usual expression plus terms proportional to $\langle(a^*+b)(a+b^*)\rangle^0$ and $\langle(a+b^*)(a^*+b)\rangle_0$, which vanish by the Lorentz conditions Eqs. (12)–(13).[1] Thus explicit use of $c_n{}^{\mathbf{k}}=(-)^n c_0{}^{\mathbf{k}}$ and ambiguities from explicit (diverging) sums over n are avoided.

[1] F. J. Belinfante, Phys. Rev. **76**, 226 (1949). [1a] *Ibid.*, p. 229.

E4. The Meson Mass Spectrum. ALEX E. S. GREEN, *University of Cincinnati.*—Several mathematical considerations have suggested that four meson masses occur in our generalized meson theory.[1] In virtual processes only every other meson behaves like a positive energy boson. One condition needed to overcome the difficulties attendant to the negative energy bosons is that the heaviest meson carry positive energy. The experimental picture of the meson mass spectrum and the properties of mesons has fluctuated rather wildly since we made our first proposals. However very recently a crystaliza-

tion of the results seems to have firmly established the existence of the μ-, π-, and τ-mesons, with the last two behaving like N.F. mesons (alternatively called Yukawa particles or positive energy bosons). Thus nature has rejected all theories which accommodate only one N.F. meson and all theories which predict an infinity of meson masses, but she has not yet been unkind to our theory when taken with the magic number four. A provocative interpretation of the experiments and the theory would suggest itself if another particle were discovered having a mass between those of the π- and τ-mesons and having the properties (no star production etc.) of the μ-meson.

[1] A. Green, Phys. Rev. **73**, 519 (1948); **75**, 1926 (1949).

E5. The Motional Capacitance of AT-Cut Quartz Resonators. KARL S. VAN DYKE, *Wesleyan University.**—Previously reported measurements on BT-cut resonators partially plated in strips had indicated that the alternating strain in the crystal is sinoidally distributed parallel to both pairs of edges for square plates whose edges are parallel to X and Z', and that the strain falls approximately to zero at both pairs of edges. Impedance measurements on square AT plates with edges similarly parallel to X and Z' indicate a distribution such that the strain falls only to 40 percent of its central value at the edges which are parallel to X. The experimental motional capacitance for the several electrode areas used are in close accord with the theoretical analysis of the accompanying paper, which then provides a theoretical as well as a practical basis for predicting the circuit behavior of such resonators with some precision. By viewing the distribution of strain which is found experimentally as resulting from the superposition of the strains of several coupled component simple resonators the secondary roles of the constants C_{11}' and c_{55}' are apparent. These govern the mechanical impedances of two such coupled resonators which in the composite bring about the departure of the actual distribution from the uniform distribution for a plate of infinite extent with mode dependent upon c_{66}'.

* Work supported by U. S. Army Signal Corps.

E6. The Theory Of Thickness-Shear Resonance of Piezoelectric Resonators. GARY D. GORDON, *Wesleyan University.** (*Introduced by K. S. Van Dyke*).—Ekstein** showed theoretically that in the fundamental thickness shear resonance of thin rectangular plates the distribution of strain along a direction perpendicular to the axis of shear is sinoidal. Hok† showed similarly that the approximate distribution along the parallel direction should be somewhere between uniform and sinoidal, in the form $\cos[(\pi\sigma_p z')/w]$. By minimizing Hamilton's Integral for this distribution, the parameter σ_p can be expressed in terms of secondary elastic constants of the material and of the length to width ratio of the plate. Known values of the constants, c_{11}' and c_{55}', for quartz yield numerical values for the parameter σ_p of 0.98 and 0.72 for square BT and AT-cut plates, respectively. The strain falls nearly to zero along the edges parallel to X in the BT plate but not in the AT. The motional capacitance for plates having fractional area electrodes computed on the basis of these theoretical distributions agrees excellently with experimental determinations, which are described in an accompanying paper.††

* Work supported by U. S. Army Signal Corps.
** H. Ekstein, Phys. Rev. **61**, 11 (1946).
† G. Hok, J. Acous. Soc. Am. **20**, 406–407 (1948).
†† Paper E5.

E7. The Dependence of the Piezoelectric Effect of $BaTiO_3$ Single Crystals on Temperature up to 160°C.* W. J. MERZ, *Massachusetts Institute of Technology.*—The behavior of the electromechanical coupling and of the piezoelectric resonant frequencies of $BaTiO_3$ was investigated by the resonance method from room temperature through the Curie point up to about 160°C. In analogy to the other ferroelectrics, the so-called single domain crystals, consisting of parallel and antiparallel domains, give very strong resonances at low frequencies, which shows that the crystal is rather soft in the directions of spontaneous deformation. The d_{31} and d_{33} coefficients increase to a high maximum a few degrees below the Curie point and then drop suddenly. Above the Curie point, maximum of the dielectric constant, we still have a piezoelectric response but it is smaller and decreases with increasing temperature. The resonance frequency traverses at the Curie point a very sharp minimum. The situation above the Curie point can be explained by the shift of the Ti ions under the influence of an external field as was verified by optical observation of the birefringence; the crystal becomes tetragonal. The effect of a d.c. bias field has also been investigated.

* Sponsored by the ONR, the Army Signal Corps, and the Air Force under ONR Contract.

E8. The Infra-red Properties of Diamond, Silicon, and Germanium. E. BURSTEIN AND JOHN J. OBERLY, *Crystal Branch, Naval Research Laboratory, Washington, D. C.*—The fundamental vibrations of the diamond structure which has O_h symmetry should be inactive in infra-red absorption. The absorption bands at 8 microns in the region of the fundamental vibration (1332 cm^{-1}) observed in Type I diamonds have been attributed to diamond structures having T_d symmetry.[1] It is suggested rather that these bands are due to the presence of impurities in the lattice of Type I diamonds. Both Type I and II diamonds exhibit bands at 5 microns. These obviously are combination bands resulting from the coupling between modes of vibration. The existence of such bands is, in fact, a striking illustration of the role played by the deformation of the electron shells during vibration.[2] The infra-red absorption spectra of silicon and germanium due to lattice vibrations should resemble that of diamond. This has now been verified by absorption measurements over the range of 2 to 25 microns. Because of their relatively high dielectric constants, silicon and germanium containing donor- and acceptor-type impurities exhibit additional absorption due to free electrons and holes which are absent in diamond at room temperature.

[1] C. V. Raman, Proc. Ind. Acad. Sci. **19**, 189 (1944).
[2] E. Burstein and J. J. Oberly, Proc. Ind. Acad. Sci. **28**, 388 (1948).

E9. New Optical Glasses Transparent in the Infra-red up to 12μ.* R. FRERICHS, *Northwestern University.*—According to Zachariasen[1] in oxide glasses polyhedra of oxygen atoms around the cations form an extended unperiodic network of open structure. The glass-forming oxides are found under the small ions of the fourth and fifth column of the periodical table. The majority of these oxides have been observed in the glassy state, but very little is known about other glass-forming compounds. Arsenic tri-sulfide forms a perfectly clear, stable red glass which has remarkable optical properties hitherto unknown. 2.6 mm of As_2S_3 pass 45 percent radiation between the red and 8μ, and this amount decreases to 21 percent at 12μ. 0.15 mm transmit 65 percent throughout this region, indicating high reflection losses due to a high index of refraction. The index of refraction $N_{Li(red)}$ is about 2.5. The glass softens at 300°C, distills without decomposition at 500°C, and is nonhygroscopic. It can be melted in Pyrex tubes and forms binary glasses with different sulfides. An investigation of this group of sulfide glasses, which have optical properties not realized in oxide glasses, is planned.

* This work was sponsored by the U. S. Navy, Bureau of Ships.
[1] W. H. Zachariasen, J. Am. Chem. Soc. **54**, 3841 (1932).

Post-Deadline Papers, if Any

FRIDAY AFTERNOON AT 1:30

Centre Theatre

(W. SHOCKLEY presiding)

Symposium of the Division of Solid-State Physics

F1. Recent Experiments on Ferromagnetic Domains and Domain Walls. H. J. WILLIAMS, *Bell Telephone Laboratories.* (30 min.)

2:05 P.M.

F2. Research on Ferroelectricity. A. VON HIPPEL, *M.I.T.* (45 min.)

2:55 P.M.

F3. Theory of Ferroelectricity. J. C. SLATER, *M.I.T.* (30 min.)

3:30 P.M.

F4. Nuclear Relaxation in Solids. N. BLOEMBERGEN, *Harvard University.* (35 min.)

FRIDAY AFTERNOON AT 2:30

Ridge Hall, East Lounge

(K. S. VAN DYKE presiding)

Miscellany in Electron Physics and Solid-State Physics

G1. Transit Time of Electrons in Simple Diodes as a Function of Current Density. DELBERT N. EGGENBERGER AND PAUL L. COPELAND, *Armour and Company and Illinois Institute of Technology.*—Calculations by Ivey[1] suggest that there is a universal function describing the variation of the field at the cathode of a vacuum tube as the current is increased to its saturation value. Since the cathode field is one of the most important data for the calculation of electron transit time in the case in which all electrons are assumed to leave the cathode with zero velocity, the equation given by Ivey may be used in such calculations. The solution of the plane parallel case presents no difficulties. For coaxial cylinders a Maclaurin's series is suggested for expressing the transit time in powers of the ratio of the current to the saturation current, and the leading terms of this series are found to be functions of the transit time in the absence of space charge.

[1] H. F. Ivey, Phys. Rev. **76**, 554 (1949).

G2. Notes on the 1P21 Photo-Multiplier Tube When Used for Astronomical Photometry. J. H. DEWITT, JR. AND C. K. SEYFERT, *Radio Station* WSM *and Vanderbilt University.*—A description is given of the operation of the Vanderbilt University stellar photoelectric photometer attached to the DeWitt 12-inch telescope. A 1P21 photo-multiplier tube and d.c. amplifier designed by Kron is used. The chief sources of troublesome leakage currents and their remedies are outlined in some detail together with a simple method for distinguishing between cell leakage current and dark current. Reduction of dark current is accomplished through refrigeration of the leads to the tube elements using solid CO_2 cylinders instead of CO_2 snow. A simple method of cutting and using the solid CO_2 is described. A 1000-volt regulated power supply replaces the batteries usually employed to provide the accelerating voltages for the 1P21 tube. A description of the power supply and a detailed parts list for it are provided. The problems involved in placing the amplifier and recording meter outside the observatory dome (i.e., cable leakage and communications) are dealt with. Finally a light curve of the eclipsing star SV Camelopardalis obtained with the instrument described is reproduced. The probable error of a single magnitude determination with this instrument on relatively bright stars (7th mag.) is ± 0.005 magnitude.

G3. Secondary Emission of Electrons at Oblique Angles of Incidence. JAMES J. BROPHY, *Illinois Institute of Technology.*—Wooldridge's theory of secondary emission[1] predicts fairly well the secondary efficiency curves for pure metals; however, the predicted emission at low energies is somewhat less than that observed. The use of an oblique angle of primary incidence serves as a more severe test of the present theory. Wooldridge's equation giving the efficiency curve has been modified for use with primary angles of incidence rather than normal incidence. The predicted results are compared with experimentally determined curves for gold, silver, and platinum, and for primary angles of incidence of 0° and 45°. The agreement is considerably worse for oblique than for normal incidence. If the difference between the observed and predicted efficiency curve is plotted against primary energy, nearly the same curve is obtained for all surfaces and both angles of incidence. This is taken to suggest that a new effect is taking place at low energies. By analogy with photoelectric emission, it is suggested that a "surface secondary emission effect" exists that together with Wooldridge's "body effect" would more completely describe the phenomena of secondary emission.

[1] D. E. Wooldridge, Phys. Rev. **56**, 562 (1939).

G4. Scintillation Counters as Detectors of Soft X-Rays.* JOHN P. NEISSEL AND DONALD C. MOORE, *Rensselaer Polytechnic Institute.*—The radiation from a copper-anode Coolidge tube, operating at 36 kv, was measured, using a photo-multiplier tube and scintillating crystal as a detector. The equipment consisted of a photo-multiplier tube and crystal, video amplifier, discriminator, and pulse counter. Types 931A and 5819 photo-multipliers were used with crystals of stilbene, calcium tungstate, and sodium iodide (with 1 percent thallium), and with no crystal. The tubes were not cooled. The x-ray beam was limited by a 3-mm diameter aperture, and its intensity was controlled by using aluminum as an attenuator. The use of crystals with the 931A reduced the sensitivity below that obtained with the tube used alone; using the tube with no

crystal, the net counting rate equalled the background rate with 1½ inches of aluminum, and this x-ray intensity required four minutes to just darken a photographic plate. The use of calcium tungstate with the 5819 reduced the sensitivity below that obtained with the tube used alone, but the sodium iodide crystal increased the sensitivity to a point where about 2½ inches of aluminum were required to reduce the counting rate to the level of the background rate; this latter intensity would require about 50 hours to just darken a photographic plate.

* Supported in part by the Rensselaer Polytechnic Institute Research Fund.

G5. The Response of the Anthracene Scintillation Counter to Monoenergetic Electrons.* JOHN I. HOPKINS,† *Oak Ridge National Laboratory.*—Using a 180-cm single-lens β-ray spectrometer to supply monoenergetic electrons, pulse height-energy studies for electrons in the 30- to 3000-kev range have been made. An extension of previously reported work[1] shows that a very definite linear relation exists between pulse height and energy for the range 125 kev to 1900 kev. The pulse height *versus* energy curve shows a decreasing slope below 125 kev and above 1900 kev for an anthracene crystal 1.29 ± 0.02 cm in thickness. If one assumes normal electron absorption in 1.55 g/cm² of anthracene one might expect a linear relation to exist up to 3100 kev. Line width studies as a function of energy have been made. The counting rate *versus* energy curves for a given electron energy follows a normal distribution curve very closely.

*This work is based on work performed for the AEC project at Oak Ridge National Laboratory.
† On leave from Vanderbilt University; J. I. Hopkins, Phys. Rev. **77**, 406 (1950).

G6. Characteristics of Scintillation Counters Using Pulsed Photo-Multipliers. R. F. POST AND N. S. SHIREN, *Stanford University.*—As a part of the electron linear accelerator program* at Stanford an effort is being made to develop high speed counting equipment. Since these accelerators operate with microsecond acceleration times it is essential for many experiments that counting, coincidence, and scaling resolving times should be much less than this. A desirable additional requirement is that the equipment should record only those events occurring during the acceleration time. It has been found possible to operate photo-multiplier counters under pulsed conditions with agreeably short resolving times. When operated with d.c. at rated voltages, the amplification factor of most photo-multipliers is about 10^6. To actuate a high speed coincidence or scaling circuit, it is then usually necessary to provide additional amplifiers, which in themselves tend to decrease the counting speed. However, operation of a photo-multiplier at higher voltages can increase its amplification greatly, so that it may not be necessary to use additional amplifiers.[1] With d.c. operation, however, a limit is reached when noise from regenerative ionization effects becomes too large to be tolerated and no further advantage is gained from raising the voltage. For pulsed operation this does not seem to be the case.

* Program supported by ONR.
[1] R. E. Bell and H. E. Petch, Phys. Rev. **76**, 1409 (1949).

G7. Luminescence of Color Centers in Lithium Fluoride. CLIFFORD C. KLICK, *Naval Research Laboratory.*—Color center absorption bands in alkali halides have been widely investigated. The present work was intended to determine whether after excitation these color centers return to their original condition by a radiationless process or by luminescent emission. X-rayed lithium fluoride showed luminescent emission in a band at 7000A when excited in the 4600A absorption band which is the *M* band for this material. Irradiation in the *F* band at 2500A did not show visible luminescence even at liquid helium temperatures. The 7000A emission of the *M* band was observed at liquid nitrogen and liquid helium temperatures as well as at room temperature. Even at liquid helium temperature the emission is several hundred angstroms wide and is not appreciably different from the emission at liquid nitrogen temperature. If the luminescent intensity of x-rayed lithium fluoride is measured as a function of the wave-length of exciting light, there is a major peak at 4600A and small peaks at 2300A, 2500A, and 3100A. The 2500A peak may represent the transformation of *F* center to *M* centers. Absorption peaks corresponding to the 2300A and 3100A excitation peaks were not observed in the present investigation.

G8. A Study of Color Centers Produced in Quartz by X-Rays. GUY FORMAN, *Vanderbilt University* AND *University of Kentucky.*—*Z* cut sections of natural quartz crystals were colored to saturation by *x* irradiation from a beryllium window x-ray tube. The crystal sections were decolored by heating and recolored by further *x* radiation. The same optical transmissions, at saturation, were obtained when the energy distribution of the x-ray beam was the same but were different when different voltages were applied to the x-ray tube. The heat treatment used in removing the color from quartz does not affect the value of the optical transmission when recolored by *x* radiation to saturation. It was observed that in every case the rate of coloration was greater after the section had been cleared and re-irradiated than when the color was being produced for the first time. If the heat treatment is restricted to an amount barely sufficient to remove the coloration, then the rate follows the same curve on successive irradiation cycles. If the crystal section is baked for a longer period of time than that stated above, the rate decreases and approaches that of fresh quartz. The change in rate of coloration of quartz is governed by the immediately preceding heat treatment employed in removing the color centers. No "memory" of previous heat treatments appears to be present.

G9. Cold Work and Particle Size Broadening in X-Ray Diffraction Lines. B. L. AVERBACH AND B. E. WARREN, *Massachusetts Institute of Technology.*—Cold work and particle size broadening in x-ray diffraction patterns have been studied by making precision measurements of peak shapes with a Geiger-counter spectrometer. The corrected shapes are represented in terms of a Fourier cosine series and a set of amplitudes, A_n, is determined. The form of the function of A_n *vs.* n distinguishes between particle size and cold work broadening. Data for particle size broadening in MgO have been obtained. The initial slope of the A_n curves gives the mean particle size and the second derivative gives directly the particle size distribution. Cold work distortion has been observed in alpha-brass filings and this has been interpreted in terms of root mean square distortions averaged over lengths, na_3. An attempt has been made to determine a distribution function of the strains by measuring several orders of a given plane.

G10. Random-Circuit Theory of Resistance and Noise in a Composition Resistor. R. P. COLEMAN, *Franklin Institute.*—Common types of resistors are made from a mixture of finely divided conducting particles in an insulating medium. A theory based on a concept of a random electrical circuit has been developed, in which the imperfect electrical contacts between conducting particles constitute the resistance elements and the conducting particles constitute the junctions between resistance elements. An expression for terminal resistance in terms of an assumed statistical distribution of local resistance values is obtained. The derivation involves an equivalent circuit representing one local resistance together with the average effect of all the remaining local resistances. The method is also applicable to the study of related properties such as temperature coefficient of resistance. If noise generation in each local region is represented by any assumed law of e.m.f. and resistance fluctuation, the corresponding noise at the terminals is given by random-circuit theory. An expression for an upper bound to resistance-fluctuation noise is also obtained.

FRIDAY EVENING AT 6:00

Oak Terrace Restaurant, Grove Centre

(I. I. RABI presiding)

Banquet of the American Physical Society

After-dinner speech

The Role of Physics in Current Atomic Energy Development. A. M. WEINBERG, *Oak Ridge National Laboratory.*

SATURDAY MORNING AT 9:30

High School Auditorium

(I. I. RABI presiding)

Symposium on Diverse Aspects of Beta-Emission

H1. Theory of Forbidden Beta-Ray Transitions. E. J. KONOPINSKI, *Indiana University.* (30 min.)

H2. Measurement of Forbidden Beta-Spectra with the Scintillation Spectrometer. P. R. BELL, *Oak Ridge National Laboratory.* (30 min.)

H3. Isomeric Transitions in Nuclei. PETER AXEL, *University of Illinois.* (30 min.)

H4. Measurement of Short-Lived Isomeric States. F. K. MCGOWAN, *Oak Ridge National Laboratory*, and S. DE BENEDETTI, *Carnegie Institute of Technology.* (30 min.)

H5. Double Beta-Decay. E. L. FIREMAN, *Princeton University* (30 min.)

SATURDAY MORNING AT 9:30

Ridge Hall, East Lounge

(F. SEITZ presiding)

Semi-Conductors

I1. Semiconductivity of Polycrystalline Graphite. S MROZOWSKI, *University of Buffalo.*—The experimentally observed dependence of the resistance of polycrystalline graphite from temperature can be explained by assuming the existence of an energy gap between the filled and conduction bands. Such a graphite is an intrinsic semiconductor at room temperature. The energy gap is so small however (25×10^{-3} ev) that at higher temperature its presence becomes immaterial and the substance shows a metallic behavior. The size of the gap increases with decreasing dimensions of crystallites. The conductivity of polycrystalline graphite at low temperatures and of fine crystalline carbons (cokes) in general are due mainly to excess electrons in the conduction band, the peripheral carbon atoms with free valences playing the role of N-centers. The complete system of resistivity curves from the low temperature cokes up to well-graphitized specimens can be understood in forms of these assumptions. The scattering of electrons due to the finite size of crystallites, lattice imperfections and so forth gives in commercial graphite a contribution to the resistivity decreasing with increase of temperature in the region of low temperature ($\sim$150°K) and tending to a constant value at higher temperatures.

I2. Electron Mobilities in Conducting Phosphors. LEE GILDART AND A. W. EWALD, *Northwestern University.*—The mobility of electrons in those semiconductors which are also phosphors can be found in a new way as follows: The crystal to be investigated is irradiated with square-wave pulses of energetic quanta (ultraviolet light or x-rays). The response of the crystal to these pulses gives (1) a conductivity rise-and-decay curve (2) a luminescence rise-and-decay curve. Analysis of these curves, which are recorded simultaneously, gives the mobility directly. Related parameters are also derivable. Measurements on a small polycrystal of cadmium sulfide gave these values: Mobility $\sim$60 cm^2/volt sec.; density of electrons in the conduction band $\sim10^{11}$ per cm^3; lifetime of an electron in the conduction band $\sim10^{-3}$ sec.; schubweg $\sim$25 cm.

I3. The Effect of Surface States on the Fermi Level of a Semiconductor. PAULA FEUER AND HUBERT M. JAMES, *Purdue University.*—Over a wide range of conditions, the number of electrons n per unit volume in the conduction band at temperature T is proportional to $\exp(\zeta/kT)$, where ζ is the Fermi level. For N-type semiconductors in the impurity range, ζ is usually determined by the condition $n+n'=N$, n' being the number of electrons in impurity states and N the number of impurities per unit volume. If electrons can also occupy surface states, the condition for determining ζ is $n+n'+n''(A/V)=N$, where n'' represents the number of electrons per unit area in surface states, A the area and V the volume of the sample. When the number of electrons on the surface becomes comparable with the number of conduction electrons, the surface term becomes important and the Fermi level is lowered. Calculations show that surface states can be important in samples of small N (e.g., 10^{16} impurities/cm^3) at low temperatures (e.g., 20°K); n is smaller and the resistivity

higher than that predicted by previous theory. This effect depends strongly on the activation energy for the electrons and is particularly large in the case of thin films, where A/V is large.

I4. A. C. Circuit for Rapid Determination of Hall Coefficients of Semiconductors.* B. R. RUSSELL, P. H. MILLER, JR., AND C. F. WAHLIG, *University of Pennsylvania.*—Direct current methods and usual alternating current methods of measuring small transverse voltages due to the Hall effect require at least two separate measurements to eliminate thermal e.m.f. or stray signals which are always present. A faster method is needed in order to make measurements upon semiconducting oxides at elevated temperatures where rapid changes in composition occur. When both the magnetic field and the current are made to alternate sinusoidally but at different frequencies, the resulting Hall voltage has two components (the sum and difference frequencies) which can be separated from one another and from stray voltages by a band pass filter. Thus the output is directly proportional to the Hall voltage and no second measurement is necessary. A test circuit based on this idea has been constructed and found to yield values of Hall coefficients which agree within experimental error (± 10 percent) with conventionally determined values. Using Cu_2O samples the signal to noise ratio is about 100 to 1 at room temperatures [$R \sim 10^{-3}$ (volt-cm/amp.-gauss), $I \sim 10^{-3} \sin 2\pi 70t$ amp., $B \sim 10^{3} \sin 2\pi 60t$ gauss, $\sigma \sim 10^{-3}$ ohm^{-1} cm^{-1}] and decreases slowly to about 7 to 1 at 300°C, R having decreased by a factor of about 60.

* Work supported in part by the Bureau of Ships.

I5. Recrystallization Purification of Germanium. R. N. HALL, *General Electric Research Laboratory.*—A recrystallization technique will be described which is very effective in the removal of impurities from germanium. Chemically purified germanium dioxide is reduced in hydrogen, vacuum melted in a graphite boat, and directionally cooled so as to concentrate the impurities in the ends of the ingot. Successive recrystallizations of the central sections remove impurities to the point where the room temperature electrical conductivity is essentially intrinsic. Impurity distributions, as determined by conductivity measurements, are consistent with an analysis which predicts that an impurity be distributed in proportion to the $(k-1)$ power of the distance from the end of the ingot which cools last, where k is the ratio of the impurity solubility in the solid phase to that in the liquid phase at the melting point. Silicon and boron are found to be more soluble in the solid phase, while nearly all other impurities show a strong preference for the liquid phase. Control of impurities makes possible the preparation and study of doped samples of known composition. Preliminary results of such experiments will be presented.

I6. Fast Neutron Bombardment Effects in Germanium. J. H. CRAWFORD, JR. AND K. LARK-HOROVITZ, *O. R. N. L.*—The concentration of lattice defects produced by a given fast integrated neutron flux (nvt) in N-type germanium semiconductors was studied assuming that each defect produces one acceptor. The number of defects produced per incident neutron may be obtained from the slope of the conductivity *vs.* nvt curve. In the initial portion of the curve—concentration of electrons very large compared to that of holes—in which the mobility remains nearly constant,

$$d/d(\text{nvt}) = -ebK, \tag{1}$$

where e is the electronic charge, b is the mobility, and K is the net number of defects produced per incident neutron which is between 1 and 5 in most cases. Due to the rate of healing of defects the rate of production of defects is given by

$$dN/dt = fK' - k_2'N^2, \tag{2}$$

where k_2' is the second-order rate constant, f is the fast flux and K' is the number of defects introduced by irradiation.

I7. Germanium Semiconductor Alloys Produced by Transmutation. J. CLELAND, K. LARK-HOROVITZ, AND J. C. PIGG, *O.R.N.L.*—Germanium exposed in a nuclear reactor becomes a P-type semiconductor. This is due to (a) lattice displacement (fast neutrons) and (b) impurity centers produced by transmutations (slow neutrons). The displacement effect can be healed out by prolonged heat treatment at 450°C. The remaining increase in P-type centers is due to the difference between Ga atoms and As atoms produced by transmutation. Using absorption cross sections on separated Germanium isotopes determined by H. Pomerance (O.R.N.L.) the predicted number of excess P-type impurity centers is about 2 percent of the integrated slow flux. Comparison between Hall effect measurements before neutron irradiation, after irradiation and finally after heat treatment shows that within the limits of error (flux measurements, absorption cross section, variations in heat treatment, one current carrier is released per impurity center produced, in agreement with former theoretical considerations.[1]

[1] Lark-Horovitz, Middleton, Miller, and Coalerstein, Phys. Rev. **69**, 258 (1946).

I8. Germanium $P-N$ Barriers as Counters.* C. ORMAN, H. Y. FAN, G. J. GOLDSMITH, AND K. LARK-HOROVITZ, *Purdue University.*—The high resistance of a $P-N$ barrier in germanium makes it sensitive to ionizations produced in the barrier. This makes it possible to use $P-N$ barriers as counters for nuclear radiations. McKay[1] has recently reported the use of point contact rectifiers as counters for alpha-particles and pointed out that such a device will respond effectively only to particles of high specific ionization. It has been found that $P-N$ barriers respond to alpha-particles from polonium and also to betas from RaE. From the pulse shape and the source strength it is evident that the pulses observed are produced by individual ionizing particles. The magnitude and time constant of the pulses depend upon the capacitance and the resistance of the barrier. The resistance of the barrier can be varied by varying the temperature; the barrier capacitance depends upon the dimensions of the crystal and can be controlled further to a certain extent in the case of the artificial barriers produced by nucleon bombardment.[2]

* Work supported by the Signal Corps.
[1] K. G. McKay, Phys. Rev. **76**, 1537 (1949).
[2] See K. Lark-Horovitz, *et al.*, Phys. Rev. **73**, 1256 (1948).

I9. Changes in Conductivity of Germanium Induced by Alpha-Particle Bombardment. W. H. BRATTAIN AND G. L. PEARSON, *Bell Telephone Laboratories.*—K. Lark-Horovitz *et al.*[1] found that the electrical conductivity of germanium can be changed by nucleon bombardment. The bombardment of 8 ohm cm n-type germanium by alpha-particles from polonium first removes the conducting electrons at the rate of 78 per alpha-particle. After the electrons are gone conducting holes are introduced at the initial rate of 8.6 per alpha-particle. Some of these holes disappear with time at room temperature after bombardment is stopped, leaving only 2 conducting holes per alpha-particle. This change takes place only to the depth of penetration of the particles, namely, 1.9×10^{-3} cm. The distribution of holes with depth is not uniform. The concentration rises from an initial value to a maximum at 1.4×10^{-3} cm depth and then falls to zero. The maximum is about 2.5 times the initial value and the integral under the curve is, of course, 2 holes per alpha-particle. The number of centers capable of removing electrons from the conduction band (traps or acceptors) is about 9 times larger than the net number of conducting holes produced by the bombardment.

[1] W. E. Johnson and K. Lark-Horovitz, Phys. Rev. **76**, 442 (1949).

I10. The Technique of Cutting Germanium Filaments. W. L. BOND, *Bell Telephone Laboratories.*—A germanium slab is etched to prove that it is a single crystal, then is diamond-sawed and ground on a carborundum belt grinder to required orientation with the help of x-rays. The blank thus produced is etched if required to have an undisturbed surface and cemented to a substrate (commonly glass). The cement is polyvinyl butyral, which after curing is not attacked by etchants or solvents, nor softened by heat. Intricate shapes are cut with a die which is oscillated vertically 6000 cycles per second, driven by a magnetostrictive drive. Emery charged water surrounds the tool and work during cutting. The tool while lifting pumps in water and emery and drives the emery into the germanium on the down stroke, thus pulverizing a thin layer of germanium. The tool and drive assembly are lowered slowly by turning a micrometer screw until its reading indicates that the tool has passed through the blank. This device produces very straight walls and sharp angles and gives fine detail.

I11. The Quantum Yield of Electron-Hole Pairs in Germanium. F. S. GOUCHER, *Bell Telephone Laboratories.*—The central portion of a long filamentary single crystal of n-type germanium is irradiated with monochromatic light of known energy, in the presence of a uniform field, E. The unilluminated ends are long in comparison with the mean range of generated holes. Under these conditions, the measured photocurrent Δi equals $NeE^2\tau_p(\mu_p+\mu_n)/V$, where N is the number of electron-hole pairs produced per second, e the magnitude of the electronic charge, τ_p the lifetime of a positive hole, μ_p and μ_n the hole and electron mobilities, respectively, and V the potential difference between the ends of the specimen. The number of quanta S absorbed per second is known from the energy, wavelength, absorption distance, and refractive index. By comparing the calculated values of N and S, the quantum yield is determined. Within the limits of experimental error, this yield is shown to equal unity.

I12. Noise in Germanium Related to Fluctuations in Hole Concentration. H. C. MONTGOMERY AND W. SHOCKLEY, *Bell Telephone Laboratories.*—Filaments of single crystal germanium carrying a d.c. current exhibit electrical noise having power per cycle bandwidth inversely proportional to frequency. Measurements at audiofrequencies in filaments of n type germanium show that the noise voltages in adjacent sections are uncorrelated when the mean life-path of holes is much shorter than the section-length, but are highly correlated when the life-path exceeds the section-length. A magnetic field produces substantial changes in noise level, which can be explained by spatial redistribution of holes in the filament under Hall effect forces with consequent variation in lifetime.[1] These results suggest that the observed noise is due to irregular variations in hole concentration in the specimen, resulting in fluctuations in conductivity and consequent modulation of the biasing current. A possible mechanism for such variation may be recombination of holes and electrons through traps and the reverse generation process; these processes for one trap may be modulated noisily by changing charges on other traps.

[1] H. Suhl and W. Shockley, Phys. Rev. **75**, 1617 (1949).

I13. The Magneto-Resistance Effect in Oriented Single Crystals of Germanium. G. L. PEARSON, *Bell Telephone Laboratories.*—The electrical conductivity in oriented single crystals of both n- and p-type germanium has been studied as a function of magnetic field strength, direction of magnetic field, and direction of electric current. Measurements were made from 10^3 to 10^5 gauss[1] at 77 and 300°K. The current flow was either along the 100 or the 110 direction and measurements were made with the magnetic field oriented in various directions. At small fields $\Delta\rho/\rho$ is proportional to H^2. The three coefficients which determine the angular dependence have been obtained. For electrons the transverse effect is the expected magnitude but there is a large longitudinal effect not given by the simple theory. For holes the longitudinal effect is very small as expected by theory, but the transverse effect is anomalously large. Theory indicates that $\Delta\rho/\rho$ is proportional to the square of the mobility. The mobility varies as T^{-1} and it is found that $\Delta\rho/\rho$ varies as T^{-2}. At high fields $\Delta\rho/\rho$ becomes linear with H. Values of ρ_H/ρ_0 as large as 3 have been observed for 10^5 gauss at 300°K and 10^4 gauss at 77°K.

[1] The measurements at high fields were made possible through the cooperation of the magnet laboratory at Massachusetts Institute of Technology.

I14. Measurements of Magnetoresistance of Germanium in very Intense Magnetic Fields. H. SUHL.—The magnetoresistance of germanium samples was measured in fields up to about 170 kilogauss. Measurements at room temperature and at 77°K were made with current and magnetic field along various crystallographic axes. Saturation of the resistance *vs.* magnetic field plot was reached in some orientations. The apparatus for producing the magnetic field consists of a bank of condensers charged slowly to about 100 volts and discharged rapidly through two ignitron tubes in series with a small coil. The field thus produced in its interior remains above 70 percent of its peak value for about 400 μsec. A voltage proportional to the magnetic field is displayed as X deflection on an oscilloscope. This voltage is obtained from an integrating circuit fed from a probe coupled into the main coil. The X deflection is then calibrated in terms of field by means of a second probe coil of known characteristics situated within the main coil. The second probe coil is then removed and replaced by the germanium sample. This is supplied with a fixed current and the voltage drop across it (which is proportional to its resistance) is displayed as Y deflection. The oscilloscope therefore plots the resistance *vs.* magnetic field, and the trace is photographed.

I15. Growth of Germanium Single Crystals. G. K. TEAL AND J. B. LITTLE, *Bell Telephone Laboratories (To be read by title).*—The growth in the number of ideas of possible conduction mechanisms of practical value that might be realized in germanium has emphasized the importance of developing specific methods of producing germanium single crystals in which the relevant properties of the material are controlled. In the present study germanium single crystals of a variety of shapes, sizes, and electrical properties have been produced by means of a pulling technique distinguished from that of Czochralski and others in improvements necessary to produce controlled semiconducting properties. Germanium is a solid that expands markedly on solidifying and is very sensitive to factors, such as physical strain, which give rise to twinning. The method of pulling the germanium single crystal progressively from the melt at such a rate as to have a stationary interface between the solid and the liquid only slightly above the liquid surface is very well suited to the material since it avoids the constraints inherent in solidifying the germanium within inflexible walls and provides a simple planar thermal gradient in the neighborhood of the interface thereby minimizing thermally induced strains. Single crystal rods up to 8 inches in length and $\frac{3}{4}$ inch in diameter and having a high degree of crystalline lattice perfection have been produced. Measurements in these Laboratories have shown the bulk lifetimes of injected carriers in these materials to be greater than 200 microseconds.

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